THE SEDIMENTARY ROCKS OF SOUTH MOUNTAIN, PENNSYLVANIA[1]

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The area described in this paper is the western portion of South Mountain, Pa., and the adjacent part of the Cumberland Valley from near the Maryland state line to the vicinty of Shippensburg, Pa. It is about 15 miles in length. The accompanying topographic map of this area (Fig. 1) is taken from the Chambersburg sheet of the United States Geological Survey and the South Mountain atlas of the Pennsylvania Geological Survey. South Mountain is the local name for the Blue Ridge which parallels the Great Valley of the Appalachian Province on the east, and Cumberland Valley, a section of the Great Valley.

TOPOGRAPHY

The Cumberland Valley is a broad, rolling lowland extending from the Potomac River to the Susquehanna River. Its general elevation is from 400 to 800 feet, and scattered, low eminences rise to 1,100 feet. These hills are usually of the rounded form characteristic of limestone country, but in part they are shale tablelands with steep escarpments. The valley has a width of approximately 13 miles in the vicinity of Harrisburg, but expands to 20 miles in the area under discussion. The southern half of the valley is drained by Conococheague Creek and its tributaries into the Potomac, the northern half by Yellow Breeches Creek into the Susquehanna.

South Mountain is a more or less irregular aggregate of ridges with a general northeast-southwest trend. Although cut across by numerous gaps, and deflected in places by sharp bends, the ridges maintain a marked continuity. The mountain front rises abruptly from the plain to elevations of 1,700 or 1,900 feet. The interior ridges are generally higher, reaching 2,100 feet in places, whence they decline again eastward into lower hills.

[1] Published by permission of the Director of the U. S. Geological Survey.

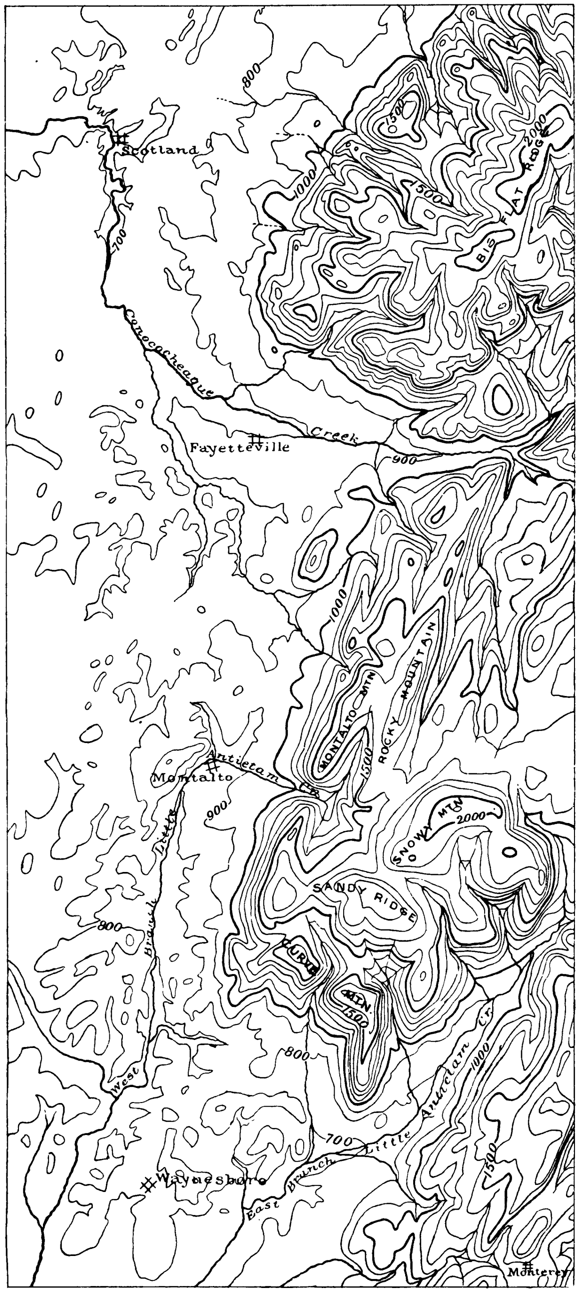


FIG. I.—Topographic map of South Mountain in southern Pennsylvania, and adjacent portion of Cumberland Valley.

From the Potomac to the Maryland-Pennsylvania state line the mountain has approximately a straight, unbroken course nearly due north. At the East Branch of Little Antietam Creek, in the southeast corner of the area shown on the accompanying map, there is an offset of the mountain front of about one mile westward, the ridges on the north side lying farther into the valley. A short distance to the north another offset into the valley, of about 2½ miles, is produced by the sharp bend of the ridges to the westward, beyond which they again assume their northeasterly course, as may be seen on the map. North of Conococheague Creek another offset of 3½ miles is produced by the development to the westward of another ridge, broad and flat-topped, and dissected by numerous deep lateral valleys. This Big Flat Ridge has an altitude of over 2,100 feet, the highest point of South Mountain in Pennsylvania.

The drainage of the mountain area is accomplished by the East Branch of Little Antietam Creek and Conococheague Creek and their tributaries. The former rises some distance east of the area represented on the map, and flows southwestward directly across the ends of the ridges on the north side of its valley, but nearly parallel to the ridges on the south side. Its tributaries are all short, and form longitudinal valleys between the ridges on the north. The West Branch of Little Antietam Creek drains a portion of the Cumberland Valley adjacent to the mountains, and has its headwaters in the short longitudinal valley which outlets at the gap east of Montalto.

Conococheague Creek heads far beyond the border of the mapped area, and, after flowing southwestward in a longitudinal valley, turns abruptly westward through a gap in the ridges. It has several large tributaries which drain the interior of the mountain area in this vicinity, chief of which are Newmans Branch, a transverse stream from the east, and Rocky Mountain Creek, a longitudinal stream from the south. Numerous short tributaries head in the deep ravines on the east flank of Big Flat Ridge. Others on the west side of the ridge find underground courses beneath the covering of wash on the surface, or sink into limestone caverns before they reach the main stream. The waters of both Conococheague and Little Antietam creeks ultimately reach the Potomac River to the south.

GEOLOGY

The rocks in this area are largely concealed by the sandstone débris which covers the mountain tops as well as the valleys and slopes. Their character, thickness, and relation are therefore not readily determined. The structure is also complicated by schistosity and jointing which exist in all these rocks. The mountains are composed of Georgian (Lower Cambrian) quartzites, sandstones, and shales, and older igneous rocks; the adjacent portions of the Valley of Cambrian and Ordovician limestones and shales.

STRATIGRAPHY

Old volcanics.—The basement rocks exposed in the area are ancient volcanic rocks, greenstone and altered rhyolite, which underlie the basal Cambrian uncomformably. They occupy the plateau-like tract overlooked by higher peaks in the center of the mountain area shown on the map and in the extreme southeast corner, and are extensively developed to the eastward. The volcanic origin of these ancient rocks is clearly shown by flow banding, amygdaloidal structure, and spherulites, as described by Williams[1] and Bascom.[2] The greenstones are sheared dense rock, veined with asbestos and chlorite. The original structure is seldom preserved, but the rock is apparently an altered basalt. The rhyolitic rocks are of purple and red tints, often porphyritic and frequently banded by flow structure or spherulitic streaks. The rhyolitic rocks predominate in this area, and apparently overlie the greenstone, for the basal Cambrian sediments are composed largely of rhyolitic fragments and not of basaltic detritus, as would be the case if the greenstone were younger and had been eroded from most of the area.

Basal sandstones.—Overlying these softer rocks are about 4,500 feet of sandstone, quartzite, and shale of Georgian (Lower Cambrian) age. The basal beds, forming the higher and more rugged portions of the mountains, are composed of coarse, purple and yellowish banded sandstones, fine conglomerate, and arkose, with white

[1] *American Journal of Science,* Third Series, Vol. XLIV, pp. 482–96.

[2] *Journal of Geology,* Vol. I, pp. 813–32, and *Bulletin of the U. S. Geological Survey,* No. 136.

feldspathic and vitreous sandstones above. The purplish conglomerate bed is composed of small pebbles and grains of quartz, feldspar, and purplish slate or tuff, the flat slaty fragments often having a diameter of 2 inches. This grades almost imperceptibly through soft purplish arkose into the reddish rhyolitic eruptives below, demonstrating their derivation largely from similar volcanic rocks exposed along the nearby shore of the Georgian sea. In Maryland, and also at Mount Holly at the north end of South Mountain, basal conglomerates contain numerous large quartz pebbles, probably in part derived from the granitic basement complex of the Piedmont.

This basal sandstone, on account of its hardness, forms high, rugged ridges in the heart of the range, such as Rocky Mountain and Snowy Mountain. It is continuous with the Weverton sandstone of the Catoctin and South mountains, Maryland, as mapped by Keith[1] and the name is therefore used here. The underlying Loudoun formation, which is described by Keith as variable in composition and thickness in Maryland, was not recognized as a distinct formation in this area, but may be represented in the soft arkose at the very base of the sedimentary series.

Upper shales and sandstones.—Above the Weverton sandstone there are about 3,200 feet of shale and soft sandstone in which are two horizons of hard, ridge-making sandstone. The softer beds are poorly exposed, being everywhere covered by the débris from the adjacent sandstones. Their presence is inferred from the fact that their outcrop is always occupied by valleys and depressions. Their character is indicated in part by occasional fragments of thin shaly sandstone and black banded slate or red ferruginous shale. The hard sandstone beds form the ridges along the mountain front and cap the high, flat-topped Sandy Ridge, as well as Big Flat Ridge north of Fayetteville. The lower of the two sandstones is the more massive, and is composed of a hard quartzitic stratum, usually of dark-gray color and veined with quartz, and a softer, granular, white layer containing long, slender *Scolithus* tubes. The upper hard bed at the top of the shale, is a milk-white or slightly pinkish, granular, calcareous sandstone, frequently disintegrating by the removal

[1] "Geology of the Catoctin Belt," *Fourteenth Annual Report of the U. S. Geological Survey*, pp. 285–395.

of the soluble cement to yellowish quartz sand, which is quarried for building purposes. This bed also contains numerous *Scolithus linearis* borings, and in places *Camarella minor* and fragments of *Olenellus*[1] have been found, by which its age has been determined to be Georgian (Lower Cambrian).

In the Catoctin and South Mountains of Maryland Keith has mapped above the Weverton sandstone 800 to 1,200 feet of shale (Harpers), and 500 to 700 feet of sandstone (Antietam). The Harpers shale is typically exposed at Harpers Ferry, on the Potomac River, and, as described by Keith,[2] consists of a bluish-gray shale with a few thin sandstone beds. Northward these sandstones beds are said to thicken, some attaining 50 feet, but do not have an appreciable effect on the topography. On the road from Monterey to Waynesboro, in the southeast corner of the area shown on the map, this series is fairly well exposed, but, according to Keith, the structure is complicated by folding and faulting. Above the Weverton sandstone in this section, as seen by the writer, are shales or slates, in part dark-banded, containing a conspicuous white, *Scolithus*-bearing sandstone 20 to 30 feet thick, all of which is mapped by Keith as Harpers shale. Above the shale is the *Scolithus* sandstone in which Walcott found *Olenellus* and *Camarella minor*, as noted above, and which is mapped by Keith as Antietam sandstone.

North of Little Antietam Creek there are two ridge-making sandstones above the Weverton sandstone, one composing Sandy Ridge and the other Curve Mountain, and between them is black-banded slate with thin ferruginous sandstones. The upper bed forming Curve Mountain is undoubtedly the Antietam sandstone, and it is apparent that one of the sandstone beds in the Harpers shale of Maryland increases in prominence northward, so that in Pennsylvania it reaches such dimensions that it forms a distinct ridge. The Harpers formation in this area therefore consists of shales and soft sandstones, with a quartzitic member near the middle which is here named the Montalto quartzite, from Montalto Mountain. Northward the shale gradually thins, and the sandstone continues to expand until at the northern border of the area it occupies

[1] Walcott, *Bulletin of the U. S. Geological Survey*, No. 134, p. 25.

[2] *Loc. cit.*, p. 308.

TABLE OF GEOLOGIC FORMATIONS FOR SOUTH MOUNTAIN, PA., AND ADJOINING PORTIONS OF THE CUMBERLAND VALLEY

Age	Name		Thickness (feet)	Character
Ordovician	Martinsburg group	Eden sandstone	500	Soft, buff to green sandstone
		Utica shale	1,000	Gray fissile shale, with black, carbonaceous and calcareous shale, probably of Trenton age, at the base
	Shenandoah group	Chambersburg limestone	1,000 +	Fossiliferous, crystalline and thin shaly limestones of Chazy-Black River age
		Stones River limestone	400 +	Homogeneous, dove-colored, pure limestones of Stones River age
Saratogan (Upper Cambrian)		Knox limestone	2,000 ±	Drab magnesian and siliceous limestones, in part cherty, with limestone conglomerate at the base
Acadian (Middle Cambrian) ?		Elbrook limestone	2,000 ±	Massive, bluish-gray, magnesian and cherty limestone with some red and green shales
		Waynesboro formation	600 ±	Purple shale and flaggy sandstones
Georgian (Lower Cambrian)		Tomstown limestone	800 ±	Drab to white magnesian and pure limestones
		Antietam sandstone	500 ±	White, calcareous, *Scolithus* sandstone, containing Georgian fossils
		Harpers formation and Montalto quartzite member	2,750 ±	Dark-banded shale or slate and ferruginous sandstone, with gray to white quartzitic sandstone, containing *Scolithus* tubes in the softer layers
		Weverton sandstone	1,250 ±	Purple to white feldspathic sandstone, conglomerate, and arkose
Algonkian ?		Old volcanics		Altered rhyolite and greenstone

almost the whole interval of the formation, indicating a gradual change from a fine mud deposit in the south to coarser siliceous sediments in the north. Similar conditions may have continued into Antietam time, and have affected the deposition of the Antietam sandstone. The patchy occurrence of the Antietam in the Maryland area, as mapped and described by Keith, may be due to its irregular

deposition in that area, instead of to infolding in the Harpers shale and to faulting, as previously supposed. Irregularity of Antietam sedimentation in the Pennsylvania area also is indicated by the absence of ridge-making character east and southeast of Montalto, where the bed is thin, disintegrated, and inconspicuous.

Shenandoah limestone.—The rocks of the Valley are chiefly light- and dark-gray, massively bedded, magnesian limestones, described and mapped in the northern Appalachian folios of the United States Geological Survey atlas as the Shenandoah limestone. They are so intricately folded, and have so few easily recognized horizons, that the details of the stratigraphy cannot be determined nor the thicknesses accurately measured. The series is estimated to be about 6,800 feet thick, and is here divided into six formations. The lowest, composed largely of drab to white, impure limestones, has near its base beds of purer, mottled, dark- and light-gray limestone, which is frequently quarried and burned for lime, and near its top a massive bed of cherty limestone. The formation is limited above by ferruginous sandstone and purple shale. It is approximately 800 feet thick. The name "Tomstown limestone," here applied to it, is from a village at the foot of South Mountain, where the formation outcrops.

The next succeeding formation is composed largely of hard, siliceous, ripple-marked, purple shale and flaggy, calcareous sandstones, about 600 feet thick. At the base is a siliceous rock weathering into large slabs and masses, stained yellow by iron, and usually banded and contorted. These masses, together with fragments of vein quartz and white porous chert, strew the surface and in places produce a low ridge. Scattered deposits of limonite occur on the slopes of these ridges, produced by the leaching of iron from the ferruginous shale and its precipitation in the soil and wash at the surface. Flaggy sandstone and sandy shale, forming the top of the formation, make a rather continuous low ridge in the limestone lowland, thus affording a marker in the otherwise monotonous series of beds. Shattered portions of this sandstone are veined with barite, and in the soils at the base of the hillslopes the weathered product has in places been concentrated and mined on a small scale. At Waynesboro, in the upper sandy shales and in the immediately overlying lime-

stones, fragments of trilobites and other fossils suggesting Acadian (Middle Cambrian) age, were found by the writer. The sandstone and the purple shale also outcrop conspicuously in the ridge just north of Waynesboro, so the name "Waynesboro formation" is suggested for this division of the Shenandoah. In central Virginia H. D. Campbell[1] recently subdivided the Shenandoah limestone into several formations, separating at the base a limestone and an overlying series of variegated shale, which he named respectively the Sherwood limestone and the Buena Vista shale. Presumably these are the same subdivisions mapped in this area, but from the data at hand this can not be determined for certain, and since it is known that a large fault and corresponding gap in the stratigraphy occur in the intervening Harpers Ferry area, new names are here proposed for the formations.

Massive, bluish-gray, magnesian limestones, with numerous thin layers and nodules of chert and beds of shale, possibly 2,000 feet in all, compose the next formation. Red and green shales are present in the middle of the formation, and beds of sandy limestone, which in places form low ridges, occur higher in the section; but none of the beds have been traced for any considerable distance. The only fossils which have been found in this portion of the section are those mentioned as occurring in the basal layers and indicating Acadian age. The name "Elbrook limestone," from a town at which the formation is quarried, is proposed.

A change to siliceous sediments with conglomerate, oölite, and red clay, marks the base of the next succeeding formation. The siliceous layers weather to granular porous sandstone, which produces a low ridge and offers another marker in the otherwise uniform limestone section. Conglomerates of rounded pebbles of dense magnesian limestone, imbedded in a matrix largely of quartz grains, indicate an elevation of a portion of the nearby sea bottom into a land area and the erosion of the limestone, the quartz sand coming from a more distant source on the land. Other conglomerates or breccias of flat fragments of thin slabby limestone variously arranged in a matrix of calcareous mud are intraformational conglomerates derived from recently deposited silt broken up by wave,

[1] *American Journal of Science*, Fourth Series, Vol. XX, No. 120, pp. 445–47.

tide, or current action. The thin fragments are often tilted on end, and resemble the "edgewise beds" of Missouri described and figured by Nason.[1] Red clay in crevices and holes of the limestone suggests surface weathering and residual clay filling solution pockets. Oölite is evidence that the water was sufficiently shallow for the waves to oscillate the particles on the sea bottom. For these reasons it is concluded that this horizon represents a break of some consequence in the sedimentation, due to uplift and erosion in this or in some immediately adjacent territory. Since this change is accompanied by the introduction of a different fauna, specimens of which, chiefly trilobites, collected at Scotland, were determined by Walcott as Saratogan (Upper Cambrian), it is regarded as representing the base of the Saratogan. Associated with the conglomerates is a minutely laminated pure limestone with parallel, wavy, dome-shaped, and contorted structures. Horizontal sections of the dome-shaped structure show regular concentric rings, whereas the vertical sections show waves with round tops and angular bottoms, as shown in Fig. 3. No internal structures were observed by which organic origin could be determined, but in a general way they resemble *Stromatopora* and may represent some low form of life which spread out on the sea bottom and secreted minute layers of lime. They are undoubtedly similar to *Cryptozoan proliferum* described and figured by Hall,[2] which occur in oölitic limestone near the base of the Saratogan in New York.[3]

The conglomerate zone, 10 to 15 feet thick, is followed by drab magnesian limestone with the same Saratogan fauna, grading upward into siliceous limestones containing occasional poorly preserved gastropods of Beckmantown age. The formation is estimated to be 2,000 feet thick. Ulrich, who has recently made a careful study of the rocks throughout the Great Valley, regards this formation as stratigraphically and faunally the same as the Knox dolomite of Tennessee, and the name "Knox limestone" is therefore adopted.

[1] *American Journal of Science*, Fourth Series, Vol. XII, pp. 358–61.

[2] New York State Museum of Natural History *Thirty-Sixth Annual Report* 1883, Plate 6 and description.

[3] Walcott, *Journal of Geology*, Vol. XI, No. 3, pp. 318–19.

The Knox is limited above by homogeneous, fine-grained, dove-colored, pure limestone, extensively quarried throughout the Valley. It contains a few leperditia, gasteropods, and brachiopods of Stones River age, and since the rock is lithologically the same as the Stones River of Tennessee, and apparently occupies the same interval, the name "Stones River limestone" is applied here.

Overlying the Stones River are darker and more crystalline limestones, somewhat cherty at the base and interbedded in the upper portion with argillaceous limestone. Fossils are not numerous in the lower cherty beds, but the upper portion contains a large and interesting fauna, referred by Ulrich to the Chazy and Black River. The formation is well exhibited along the edge of the shale belt west of Chambersburg, and is therefore named the "Chambersburg limestone." The thickness of this and the Stones River formation was not determined by the writer. Sections recently made by Ulrich near Greencastle, 8 miles west of Waynesboro, show 400+ feet of Stones River limestone and 1,000+ feet of Chambersburg limestone.

The Martinsburg group.—The calcareous strata are followed by a series of shales and soft sandstones previously called the "Martinsburg shale." At the base are a few feet of dark calcareous shale and thin beds of carbonaceous limestone, transition beds, containing a fauna regarded as Trenton in age. These are followed by dark to gray platy shale, with *Leptobulus insignia*, *Triarthus becki*, and other Utica forms, including numerous graptolites, and it is therefore named the "Utica shale." It is generally intricately folded and crinkled, but the thickness is estimated to be 1,000 feet. Above it are greenish to buff, soft sandstone which is named Eden because it contains a fauna referred by Ulrich to the Eden, and is regarded by him as stratigraphically its equivalent. It has a thickness of about 500 feet. These shales and sandstones form the tablelands rising out of the limestone lowland west of Chambersburg.

STRUCTURE

All the rocks of the region have been folded and highly compressed, and nearly all have acquired a secondary structure. In the mountains the rocks have a marked schistosity, most completely

developed in the soft shales and feldspathic rocks, but even the hardest quartzites have parallel jointing and to some extent are schistose. The strike of the schistosity is parallel to the ridges, and the average dip is 35° southeast. In most cases this is the dominant structure, often producing a banding which closely resembles bedding and entirely obliterates the true stratification. It is not surprising, therefore, that many of the early geologists, mistaking the schistosity for bedding, failed to understand the relations. The stratification can be determined in the *Scolithus*-bearing rocks because it is perpendicular to the worm-tubes, and in the coarser sandstones and conglomerates it is sometimes shown by alternations of coarse and fine material or by color-banding. The dips are thus observed to be usually either vertical or steep to the west. The sandstone series is found to dip away from, and therefore to overlie, the volcanics, and to pass steeply beneath the limestone of the valley along the west front of the mountain. A similar highly inclined sandstone series on the east side of the volcanic rock belt is mentioned by Walcott in his paper on the Cambrian rocks of Pennsylvania.[1] The structure of the mountain belt as a whole is therefore a broad anticlinorium.

East of Montalto.—The general structure of the mountains east of Montalto is a flat-topped, steep-sided anticline, with the east limb not exposed in the area. The ancient volcanic rocks exposed in the low plateau at the eastern edge of the area are overlain by the flat-lying, purple, feldspathic sandstones of Snowy Mountain. These sandstones may also be seen in the mountain north of the volcanic area, beyond Conococheague Creek. Westward the strata bend down sharply, and their upturned edges form Rocky Mountain, one of the few really rugged heights in this area. The shale valley in which the West Branch of Little Antietam Creek has its source is followed by the *Scolithus* sandstone of Montalto Mountain, which dips steeply to the west. At the foot of the mountain soft, calcareous, *Scolithus*-bearing (Antietam) sandstone is followed by gray and mottled limestones, with vertical and steeply overturned dips. Farther out in the valley the limestones are found to be closely folded.

[1] *Loc. cit.*, p. 24.

Northward a minor sandstone ridge forks at an acute angle from Montalto Mountain in strike with the soft calcareous sandstones at the foot of the ridge opposite Montalto. This seems to indicate that the Antietam sandstone is variable in thickness and hardness, as previously stated; but its failure to make a separate ridge at this point may in part be due to shearing along this highly compressed zone. The increased width of the shale valley to the north is due largely to flatter dips. The occurrence of brown iron ore in the residual clays along the mountain front, once so extensively mined in the vicinity of Montalto, has been considered by some as evidence of the existence of a great fault here. Similar ore deposits occur all along the mountain front, however, even around the ends of folds where faulting cannot have occurred, as will be demonstrated below, and are evidently produced by the leaching of iron from the ferruginous shales and sandstone of the mountain rocks and its precipitation, either by humic acid in bogs along the foot of the mountain, or by chemical action with the limestone with which the deposits are usually associated.

The Waynesboro fold.—Northeast of Waynesboro, where the mountain bends sharply to the east, the low hills of the valley are seen to curve first to the east and then to the south, roughly parallel to the offset in the mountain. The rocks of both the mountain and the valley ridges are found to trend and curve in the same direction as the ridges; i. e., the southwest strikes change abruptly to east, and even northeast, and then to the south again. The dips in this curved portion change from 60° W. to 20° S. Beyond, the ridges and the rocks resume their straight southward course for a short distance. It is thus seen that the offset in the mountains at this point is due to a sharp anticline and flat syncline plunging steeply to the southwest, the axis of the syncline passing through Sandy Ridge and Snowy Mountain. The parallelism and low accordant dip of the limestones of the valley and the mountain rocks throughout this fold, and the absence of any stratigraphic break, are conclusive evidence that no fault exists along the front of the mountain at this point.

The East Branch fault.—The East Branch of Little Antietam Creek flows in a limestone valley extending into the mountains

several miles. The limestones strike northeast, approximately parallel with the ridges on the south side, but diagonally across the trend of the sandstone ridges on the north, which terminate abruptly. This condition is the result of a fault cutting off the quartzite beds along the north side of the re-entrant valley and offsetting them several miles to the east. The fault apparently marks the axis of a fold, similar to that just described east of Waynesboro, in which a sharp anticline, followed to the southeast by a deep syncline, was compressed so closely that the anticline was entirely sheared out, and the limestone in the syncline now rests against the edges of the broken quartzite beds.

Big Flat anticline.—Big Flat Ridge, north of the Conococheague, is a broad, flat-topped anticline which to the north, beyond the quadrangle, forms the major part of the mountain range. A line of small knolls, composed of the *Scolithus*-bearing Antietam sandstone and dipping from 50° to 70° to the northwest, skirts the western foot of the mountain. An inner row of higher knobs is composed largely of vitreous non-*Scolithus* rock, the Montalto quartzite member. The upper shale of the Harpers formation is thin in this ridge, and the sandstone member more prominent. Apparently the shale is gradually replaced to the north by sandstone, which becomes the major part of the formation. The counterpart of the line of knobs is found on the eastern side of the ridge, composed of similar rocks and with dips of 45° to the southeast. At the south end of the mountain the same rocks bend around parallel to the southern face and dip 20° to the southwest, abruptly ending the anticline. On the crest of the ridge the beds, where exposed, indicate gentle folds, and over the level surface of the mountain top the rock fragments are chiefly *Scolithus* sandstone, apparently of the Montalto horizon. The deep ravines intersecting the anticline may cut through the Montalto quartzite member into the lower shale of the Harpers, but in no place was the underlying Weverton sandstone observed.

Beyond the end of this plunging anticline the valley rocks for several miles are hidden by wash, but from exposures farther to the southwest they are seen to be intricately folded. Whereas the hard massive sandstone beds of the mountain form one bold broad

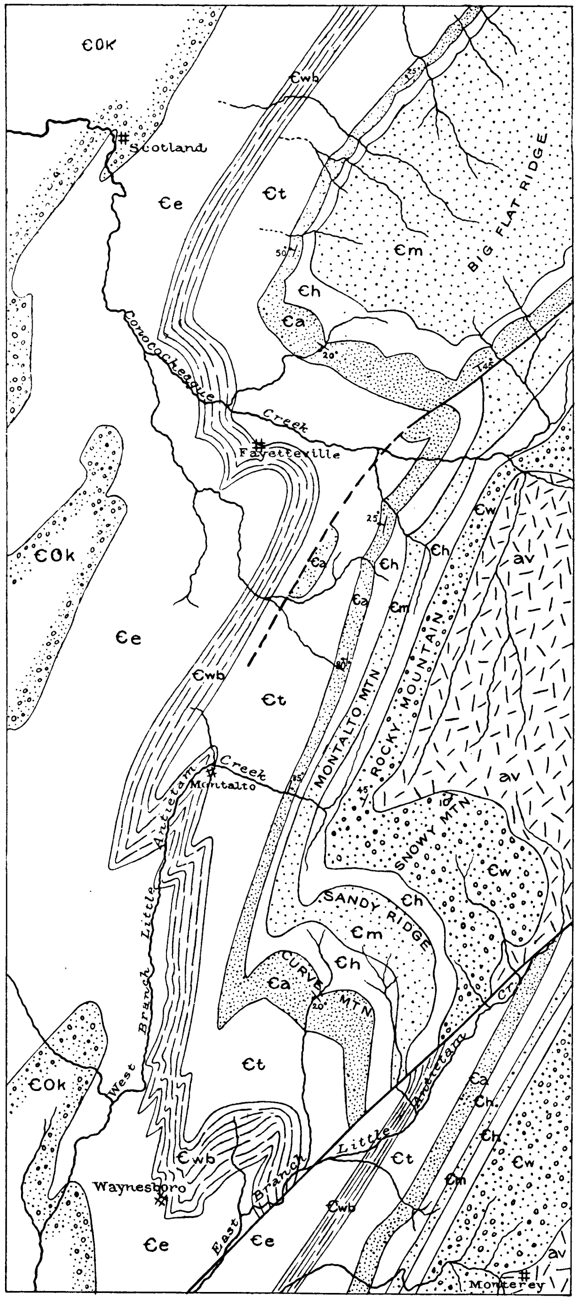


Fig. 2.—Geologic map of South Mountain in southern Pennsylvania, and adjacent portion of Cumberland Valley. *COk*, Knox limestone; *Ce*, Elbrook limestone; *Cwb*, Waynesboro formation; *Ct*, Tomstown limestone; *Ca*, Antietam sandstone; *Ch*, Harpers formation; *Cm*, Montalto quartzite member of Harpers formation; *Cw*, Weverton sandstone; *av*, ancient volcanics.

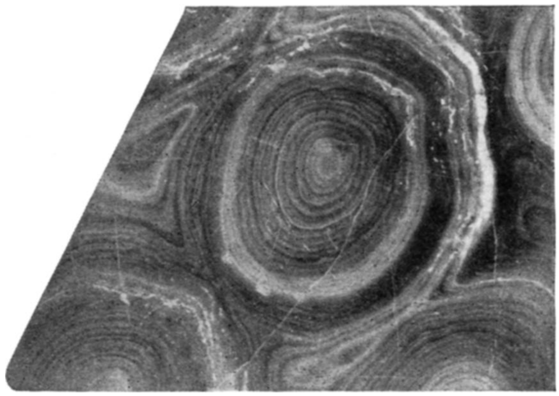
arch, the limestones around the pitching end are crumpled into numerous close folds, as may be seen on the geologic map, Fig. 2.

Just east of this Big Flat arch the Antietam sandstone, containing *Scolithus* and fragments of *Olenellus*, is crushed to a coarse breccia and cemented by iron. This crushed zone is the closely compressed, faulted syncline between the Big Flat and Montalto arches, and apparently the quartzite of Little Mountain is brought to the surface along this line of fracture by a minor anticline.

Origin of the structures.—It has been shown that the general structure of this part of South Mountain is a flat-topped arch, with the sedimentary beds on the western flank disposed as a steep monocline, dipping away from the older volcanics in the heart of the range, and beneath the limestones of the valley. This simple structure is complicated at several points along its strike by secondary folds, giving rise at their pitching ends to offsets in the mountain front.

The steep, often overturned, dips of the western limbs of the anticlines both in the mountain and valley rocks indicate that the crustal movement was to the west, and that the compressive force at the surface came from the east. This conclusion is also borne out by the schistosity dipping 35° to the southeast. The ultimate force, however, may have acted as a deeper-seated stress from the northwest. According to the theory of isostatic adjustment, the loading of the sea bottom during all of Paleozoic time would produce a deep-seated flowage toward the land. Isostasy need not, however, be depended on to account for such movement, for the thousands of feet of sediments in themselves represent an equivalent sinking of the sea bottom, whether the result of loading or of some independent cause. This landward motion would be transmitted in a certain degree to the overlying sediments, and they would be moved, by a force acting from below and from the northwest, against the consolidated land mass as a buttress, which would produce a resistant force in the opposite direction acting at the surface. The buttress in this case would be the Archean rocks of the Piedmont to the southeast, now partially covered by Triassic sediments. Thus we should have exhibited at the surface structures produced by the resistant stresses from the southeast, i. e. folds overturned to the northwest and schistosity dipping to the southeast.

At the north, opposite Fayetteville, a massive anticline rose to the west of the main axis and barred the way to further movement



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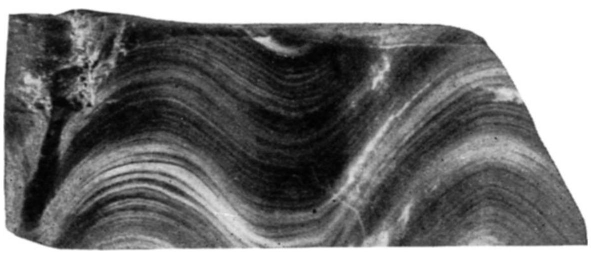

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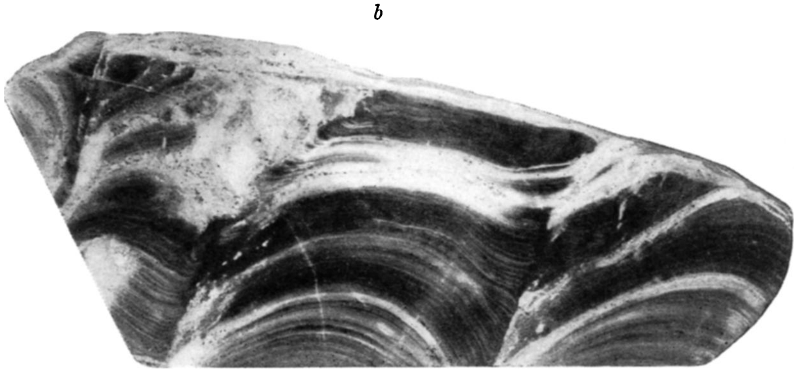

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FIG. 3.—Cryptozoan proliferum, from base of Knox limestone west of Fayetteville. Natural size. *a*, horizontal section, under side; *b*, cross-section of specimen *a; c*, cross-section of another specimen.

along the main axis in that direction. South of this point, however, by the yielding of the limestones of the valley in close folds, the rocks of the mountains moved bodily to the west, past the end of the anticline, thus causing a deflection of the trend of the axis of the main uplift behind this barrier, as may be observed by the change in direction of ridges on opposite sides of Conococheague Creek.

Earlier views.—The views of earlier writers on the geology of South Mountain are concisely summarized by Keith in his paper on the Catoctin belt.[1] These opinions were somewhat diverse. The two classes of rock composing the mountain were clearly distinguished by them all, and the igneous origin of the schists was generally recognized. The prevailing conclusion of the earlier writers, however, was that the sandstones of the mountain front dip eastward beneath the schists, and are therefore older, and probably Archean, and that a great fault exists along the west foot of the mountain. These views were held as late as 1892 by Lesley, who constantly refers in his final report[2] to the "lower or quartzite conglomerate slate series" and "the overlying feldspathic, micaceous, chloritic series,' thus reaffirming the interpretation of the stratigraphy and structure published in earlier volumes.

In this same year Walcott[3] found fossils in the uppermost layers of the sandstone series in the southeast corner of the area under discussion and in other parts of South Mountain, which, together with stratigraphic observations cleared up the stratigraphy and structure. The sandstone series was observed to overlie the orthofelsites and was proven to be of Georgian age. This view was confirmed, on structural evidence, by Keith in his paper on the Catoctin belt,[4] although he found the structures in the area to the south much more complicated by faulting than they are in this area.

Lesley, in discussing the offsets in the mountain front, says:[5]

> This geographical eschelon arrangement of the South Mountains is a good indication of their geological structure It renders it probable that the strata, whatever may be their age, have been thrown into a series of anticlinal and synclinal waves entirely analogous to those with which the Paleozoic country of middle Pennsylvania have made us so well acquainted.

[1] *Loc. cit.*, pp. 318–20.

[2] Pennsylvania Geological Survey, *Final Report*, Vol. I, pp. 144–46.

[3] *Loc. cit.* p. 24. [4] *Loc. cit.*, pp. 321–23. [5] *Loc. cit.*, pp. 143–45.

Thus far his conclusion is good, but inasmuch as the sandstone series along the mountain front is, according to his interpretation, older than the orthofelsite series, and dips away from the limestone of the valley, he concludes further that

A master fault must therefore run along the northwest foot of the mountains, along the low drift-filled valley of Yellow Breeches Creek [Mount Holly area], in which nowhere can any rock be seen in place, but only a series of brown hematite iron ore deposits, some of them of great size and once extensively mined in open quarry work. The northwest face of the mountain mass is therefore in fact the eroded basset edge of the quartzite series dipping away from the fault. The thickness of the quartzite and conglomerate series may be imagined from cross-section No. 10, laid 2½ miles north of Greenwood [east of Chambersburg], along which for five miles quartzite beds on a prevailing southeast dip are either seen or indicated suggesting a total thickness of 14,000 feet [a partial measure of the throw of the "master fault"].

Walcott accounts for the mountain offsets chiefly by thrust-faulting, as expressed in the following extract:[1]

My impression is that these offsets [in the mountain front], and also the complicated structure of the mountain, arise partly from folding, but more largely from the westward thrusts of masses of strata along the lines of fault of a low hade. This westward thrusting on the fault plane, complicated by previous folding of the strata, leaves masses of the subjacent, pre-Paleozoic rocks resting, in various places, on different members of the Lower Cambrian series, and also appears to interbed the quartzites and schists of the Cambrian in the schists, eruptive, etc., of the Algonkian.

Keith also holds the view that strike faults have a prominent part in the structure of the mountains, especially along the western border. He shows their presence in the Catoctin belt,[2] and carries them into the area southeast of East Branch of Little Antietam Creek.

CONCLUSION

It has been demonstrated in this paper that the conclusions of the writers quoted above are not applicable to the area here discussed; that thrust-faulting cannot account for the offsets in the mountain front near Fayetteville and opposite Waynesboro, but that they are due to folds plunging steeply to the south, with the strata in unbroken sequence; that along the straight portions of the mountain front the youngest beds of the sandstone series are next to the

[1] *Loc. cit.*, p. 27. [2] *Loc. cit.*, pp. 358–62.

limestone of the valley; that they appear to be in comformable sequence with dips varying from low west to steeply overturned; and that, if faulting occurs along these lines, it is of minor importance. The fault producing the deep re-entrant valley of East Branch of Little Antietam Creek and the corresponding offset of the ridges, a thrust of considerable magnitude, does not follow the front of the mountain, but strikes at an acute angle into the valley. The same is true of the crushed and faulted zone north of Conococheague Creek.